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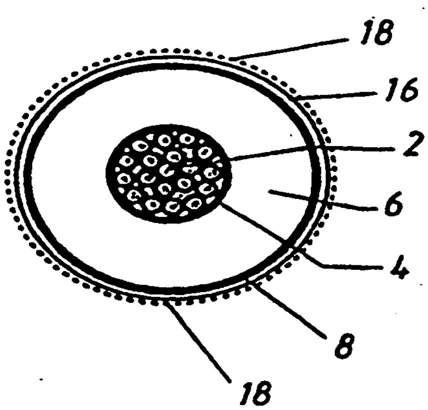
(57) Abstract

In an electric cable, designed for an electric winding, such as a transformer or reactor winding, an electrically conducting core (2) is arranged to be in contact with an inner, first semiconducting layer (4) surrounding the core. A first insulating layer (6) is arranged on the outside of the first semiconducting layer surrounding it. An outer, second semiconducting layer (8) is arranged on the outside of the first insulating layer surrounding it. Means (16, 18) are also provided on the outside f the second semiconducting layer to earth the cable for alternating voltage and/or impulse voltage continually along at least a substantial part of its length.



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A CABLE FOR ELECTRICAL WINDING, AND SUCH A WINDING

The present invention relates to an electric cable designed for an electric winding, such as a transformer or reactor winding, and a dry transformer or a reactor or inductor with such a winding.

In all transmission and distribution of electric energy transformers are used for enabling exchange of electric energy between two or more electrical systems. Transformers are available for powers ranging from the VA region up to the 1000 MVA region. With respect to the voltage range a spectrum of up to the highest transmission voltages are used today.

The transformers referred to in the present invention are so-called power transformers having rated outputs from a few hundred kVA up to more than 1000 MVA and rated voltages of from 3 - 4 kV up to very high transmission voltages.

In generally the main task of a power transformer is to enable the exchange of electric energy, of mostly differing voltages but with the same frequency, between two or more electrical systems.

A conventional power transformer comprises a transformer core made of laminated oriented sheets, normally of silicon iron. The core consists normally of a number of core legs connected by yokes. A number of windings are provided around the core legs, referred to as primary, secondary and regulating windings. In power transformers these windings are practically always arranged in concentric configuration and distributed along the length of the core leg.

Conventional power transformers for the lower parts of the above mentioned power ranges are at times manufactured with

air-cooling for the removal of inevitable losses. The transformer may be provided with an outer casing, which in turn is provided with ventilating openings, in order to be protected from contact and possibly reduce the external magnetic field of the transformer.

Most conventional power transformers are, however, oil cooled and then as a rule by means of so-called forced oil cooling. One of the reasons for this is that the oil serves as an insulating medium which is a very important function. An oil-cooled and oil-insulated conventional power transformer is therefore to be enclosed in an outer tank which has to meet very high requirements.

Conventional oil insulated power transformers also exists where the oil is water cooled.

There are several disadvantages with such oil filled conventional power transformers. Among other things an outer tank is needed in which the transformer is to be contained, the latter consisting of a transformer core with coils, oil for insulation and cooling and different types of mechanical support means. The tank has to meet very high mechanical requirements since prior to filling the transformer with oil it is necessary that it be vacuum treated to almost absolute vacuum. The need for an outer tank implies very time-consuming manufacturing and testing procedures. A tank implies also rather large outer dimensions. The large outer dimensions entail also, as a rule, great transport problems. Transformers are also, as a rule, provided with a complicated forced oil-cooling. For electrical connection between the outer connections of the transformer and the nearest connected coils/windings there is a bushing fixed to the

tank which must meet the insulation requirements which occur both on the inside and the outside of the tank.

For so-called dry transformers there are restricting upper limits for power and rated voltage, due to insulation problems and the difficulties of effectively removing the heat losses from the windings.

A conductor is known through US 5,036,165, in which the insulation is provided with an inner and an outer layer of semiconducting pyrolized glassfiber. It is also known to provide conductors in a dynamo-electric machine with such an insulation, as described in US 5,066,881 for instance, where a semiconducting pyrolized glassfiber layer is in contact with the two parallel rods forming the conductor, and the insulation in the stator slots is surrounded by an outer layer of semiconducting pyrolized glassfiber. The pyrolized glassfiber material is described as suitable since it retains its resistivity even after the impregnation treatment.

The purpose of the present invention is to provide an electric cable having solid insulation of similar construction as cables for power distribution, intended for electric windings, which cable enables improvement of a.o. performances of dry transformers. It is also the purpose of the invention to provide an electric winding of such a cable as well as to provide a dry transformer and a reactor or inductor comprising such windings.

This purpose is achieved by a cable as defined in claim 1, a winding as defined in claim 21, a transformer as defined in claim 25 and an inductor as defined in claim 26.

The cable according to the invention can withstand very high voltages and due to its outer semiconducting layer and means to connect this layer to earth if needed, the potential of the winding cable with reference to its environment may be defined, both for alternating voltages and/or for impulse voltages which is a significant advantage as metallic components in for example power transformers are normally connected to a given earth potential. With a cable according to the invention a continuous earthing of the cable is also achieved, both for alternating voltages and impulse voltages, without the use of special contacting means as in the case of earthing in discrete points. The largest part of the total voltage is applied across the insulation of the cable. Between the outer semiconducting layer and earth only alternating voltages of the order of 100 V and impulses of the order kV may appear.

According to an advantageous embodiment of the cable according to the invention the insulation, between an outer, second semiconducting layer and an earthed conductor arranged thereon, is in the form of a band made of insulating tape, extending along the cable where the earthed conductor is applied as a band divided into separated parts, arranged onto the insulating tape. By dividing the earthed conductor into separated parts in this way, short circuiting of the induced voltage is prevented.

According to another advantageous embodiment of the cable according to the invention said means for earthing comprise a second insulating layer, arranged on the outside of the second semiconducting layer, and an electrically conducting outer layer connected to earth, which surrounds the second insulating layer forming a capacitance together with the second semiconducting layer, which is significantly larger

than the cable capacitance. In this way the outer semiconducting layer is forced into a low voltage by capacitive voltage division.

According to still another advantageous embodiment of the cable according to the invention the insulation comprises an insulating tape wound around the second semiconducting layer and the earthed conductor comprises an outer casing of electrically conducting material connected to earth, said tape being wound in separated turns with a space provided between each turn and/or openings are provided in the tape so that air filled spaces are formed between the second semiconducting layer and the casing, which air filled spaces form discharge gaps in order to divert voltage impulses from the second semiconducting layer if their voltage exceeds the predetermined limit. Such an embodiment, particularly with relatively small openings, results in a robust construction. By also dimensioning the tape such that a capacitance is formed between the outer casing and the second semiconducting layer, which is significantly larger than the cable capacitance, it is ensured that the second semiconducting layer is continuously close to earth potential for alternating voltages.

According to other advantageous embodiments of the cable according to the invention the outer layer and the outer casing have circular cuts at predetermined positions along the cable. Alternatively the outer casing is in the form of separated rings of electrically conducting material around the insulation, applied separated at predetermined positions along the cable. This hinders short circuit loops in the winding which is formed by the cable.

According to a further advantageous embodiment of the cable according to the invention the diameter is within the interval of 20 - 200 mm and the conductor area is within the interval of 80 - 3000 mm^2.

In a power transformer/inductor according to the invention the windings are preferably composed of cables having solid, extruded insulation, of a type now used for power distribution, such as XLPE-cables or cables with EPR-insulation. Such cables are flexible, which is an important property in this context since the technology for the device according to the invention is based primarily on winding systems in which the winding is formed from a cable which is bent during assembly. The flexibility of a XLPE-cable normally corresponds to a radius of curvature of approximately 20 cm for a cable 30 mm in diameter, and a radius of curvature of approximately 65 cm for a cable 80 mm in diameter. In the present application the term "flexible" is used to indicate that the winding is flexible down to a radius of curvature of the order of four times the cable diameter, preferably eight to twelve times the cable diameter.

The cable according to the present invention is constructed to retain its properties even when bent and when subjected to thermal stress during operation. It is vital that the layers retain their adhesion to each other in this context. The material properties of the layers are decisive here, particularly their elasticity and relative coefficients of thermal expansion. In a XLPE-cable, for instance, the insulating layer consists of cross-linked, low-density polyethylene, and the semiconducting layers consist of polyethylene with soot and metal particles mixed in. Changes in volume as a result of temperature fluctuations are completely absorbed as changes in radius in the cable and, thanks to the com-

paratively slight difference between the coefficients of thermal expansion in the layers in relation to the elasticity of these materials, the radial expansion can take place without the adhesion between the layers being lost.

The material combinations stated above should be considered only as examples. Other combinations fulfilling the conditions specified and also the condition of being semiconducting, i.e. having resistivity within the range of 10^{-1}-10^{6} ohm-cm, e.g. 1-500 ohm-cm, or 10-200 ohm-cm, naturally also fall within the scope of the invention.

The insulating layer may consist, for example, of a solid thermoplastic material such as low-density polyethylene (LDPE), high-density polyethylene (HDPE), polypropylene (PP), polybutylene (PB), polymethyl pentene (PMP), cross-linked materials such as cross-linked polyethylene (XLPE), or rubber such as ethylene propylene rubber (EPR) or silicon rubber.

The inner and outer semiconducting layers may be of the same basic material but with particles of conducting material such as soot or metal powder mixed in.

The mechanical properties of these materials, particularly their coefficients of thermal expansion, are affected relatively little by whether soot or metal powder is mixed in or not - at least in the proportions required to achieve the conductivity necessary according to the invention. The insulating layer and the semiconducting layers thus have substantially the same coefficients of thermal expansion.

Ethylene-vinyl-acetate copolymers/nitrile rubber, butyl graft polyethylene, ethylene-butyl-acrylate-copolymers and

ethylene-ethyl-acrylate copolymers may also constitute suitable polymers for the semiconducting layers.

Even when different types of material are used as base in the various layers, it is desirable for their coefficients of thermal expansion to be substantially the same. This is the case with combination of the materials listed above.

The materials listed above have relatively good elasticity, with an E-modulus of E < 500 MPa, preferably < 200 MPa. The elasticity is sufficient for any minor differences between the coefficients of thermal expansion for the materials in the layers to be absorbed in the radial direction of the elasticity so that no cracks or other damage appear and so that the layers are not released from each other. The material in the layers is elastic, and the adhesion between the layers is at least of the same magnitude as the strength of the weakest of the materials.

The conductivity of the two semiconducting layers is sufficient to substantially equalize the potential along each layer. The conductivity of the outer semiconducting layer is sufficiently large to contain the electrical field in the cable, but sufficiently small not to give rise to significant losses due to currents induced in the longitudinal direction of the layer.

Thus, each of the two semiconducting layers substantially constitutes one equipotential surface, and these layers will substantially enclose the electrical field between them.

There is, of course, nothing to prevent one or more additional semiconducting layers being arranged in the insulating layer.

According to the invention a dry transformer is also produced having at least one cable winding according to the above mentioned. A dry transformer is hereby obtained, which is able to operate at significantly higher voltages enabling effective cooling so that the transformer is able to tolerate high powers. A transformer may also be mounted conveniently on site, i.e. the core and windings may be transported separately which minimises transport problems.

In order to explain the invention in more detail preferred embodiments of the cable according to the invention will now be described in more detail with reference to the accompanying drawings in which:

figure 1 shows a perspective view of the end of a first embodiment of a cable, according to the invention, provided with means for earthing the cable for impulse voltages,

figure 2 shows the corresponding equivalent electrical circuit,

figure 3 shows a cross-section of a second embodiment of the cable, according to the invention, provided with means for earthing the cable for alternating voltages,

figure 4 shows the corresponding equivalent electrical circuit,

figure 5 shows a perspective view of the end of a third embodiment of the cable, according to the invention, provided with means for earthing the cable for both impulse voltages and alternating voltages,

figure 6 shows a winding of an embodiment of the cable according to the invention, and

figure 7 shows a winding of another embodiment of the cable according to the invention.

Figure 1 shows a perspective view of an end of an embodiment of the cable according to the invention. The cable comprises a conducting core 2, consisting of a plurality of strands of electrically conducting material, for example copper. The core 2 is arranged in the centre of the cable and around the core there is an inner first semiconducting layer 4. Around the first semiconducting layer 4 there is arranged an insulating layer 6, of for example XLPE-insulation. Around the insulating layer 6 there is arranged an outer, second semiconducting layer 8. On the outside of the outer second semiconducting layer 8 there is arranged an insulating tape 10 along the cable. On the insulating tape there is applied an electrical conductor in the form of a band 12 made of electrically conducting material, such as metal. The conductor 12 is also earthed in a suitable manner.

Figure 2 shows for this embodiment of the cable according to the invention, an equivalent electrical circuit where the voltage on the core 2 of the cable is denoted by U, the cable capacitance is denoted by C_c and the discharge gap 14 is located between the outer, second semiconducting layer 8 and the conductor 12.

If, thus the size of a voltage impulse occurring on the outer second semiconducting layer 8 exceeds the breakdown voltage of a discharge gap 14 a short circuit is effected between the outer, second semiconducting layer 8 and the conductor 12, via air gaps between said means, and the outer, second semiconducting layer 8 is connected accordingly hereby to earth, i.e. the voltage impulse is diverted to earth.

In order to prevent short circuiting of induced voltages, the conducting band 12 is divided into separate parts which may each be earthed separately.

Figure 3 shows a second embodiment of the cable according to the invention where a relatively thin second insulating layer 16 is arranged on the outside of the second semiconducting layer 8. On the outside of the second insulating layer 16 there is also arranged an electrically conducting outer layer 18 connected to earth which surrounds the second insulating layer 16 forming an earthing capacitance together with the second semiconducting layer 8. The outer layer 18 consists preferably of metal.

Figure 4 shows an equivalent electrical circuit to the embodiment of the cable shown in Figure 3. In the same way as in Figure 2 the voltage on the core 2 of the cable is denoted by U and the cable capacitance is denoted by C_c whereas the earthing capacitance between the second semiconducting layer 8 and the outer layer 18 is denoted by C_G. As the earthing capacitance C_G is significantly larger than the cable capacitance C_c the potential of the second semiconducting layer 8 will remain close to earth potential by means of the capacitive voltage division between the voltage U on the core 2 of the cable and the earth potential which is on the outer layer 18.

The outer layer 18 may be earthed for every winding turn if each turn is separated by a certain distance.

Figure 5 shows an end of an embodiment of the cable according to the invention where an electrically insulating tape 20 is wound around the cable on the outside of the second semiconducting layer 8. The tape 20 is wound with inter-

spaces 22 and relatively small openings 24 are provided in the tape 20. On the outside of the tape 20 there is arranged an electrically conducting outer casing 26, which is connected to earth. The outer casing 26 is preferably made of metal foil.

Air filled spaces are formed between the second semiconducting layer 8 and the outer casing 26 forming discharge gaps between the turns of the tape 20 and at the openings 24, which divert occurring voltage impulses away from the second semiconducting layer 8 to the outer casing 26 and earth if the impulse voltage exceeds a predetermined limit.

The described embodiment may of course be modified, so that air filled spaces forming discharge gaps exist only between the turns of the tape, i.e. no openings are provided in the tape, or the tape may be wound tightly, so that there are discharge gaps only through the openings in the tape. An embodiment with relatively small openings renders a very robust construction.

Cuts at predetermined intermediate positions are provided in the outer layer in order to prevent short circuiting of the wound cable. Figure 6 shows a winding of a cable according to the invention, in which the adjacent winding turns 28 are in contact with each other and the cuts 30 in the cable casing are arranged at the same location for each cable turn 28. An interruption is hereby achieved in the outer casings across the whole winding and the outer layer of the winding needs only be earthed at one end 32 of the winding.

Figure 7 shows a winding with an embodiment of the cable where the outer casing is formed as rings 36 of conducting material which rings surround the insulation. These rings 36

are arranged at predetermined locations along the cable, and the insulating spaces 38 between the rings 36 are broader than the rings 36.

When manufacturing a winding of the cable according to figure 7, a cable is wound such that rings 36 of adjacent winding turns are in contact with one another in such a way that the rings form at least one continuous electrical connection across the winding. In the embodiment according to figure 7 there are two such electrical connections across the winding, which are earthed at 38 and 40 respectively. At the ends of the winding, two isolated rings, which are also earthed, are shown at 42 and 44.

If, during the manufacture of a winding as shown in figure 7, it should happen that a ring is placed in the space between two rings of the adjacent winding turns, so that electrical contact is not established between the adjacent turns, this will normally not result in damages due to the relatively low voltage between the adjacent turns, which is of the order 50 - 100 V.

CLAIMS

1. An electric cable, designed for an electric winding, **characterised** in that an electrically conducting core (2) is arranged to be in contact with an inner, first semiconducting layer (4) surrounding the core, that a first insulating layer (6) surrounding the first semiconducting layer is arranged on the outside of the first semiconducting layer, that an outer second semiconducting layer (8) surrounding the first insulating layer is arranged on the outside of the first insulating layer, and that means (10, 12; 16, 18) are arranged on the outside of the second semiconducting layer to earth the cable for alternating voltage and/or impulse voltage continually along at least a substantial part of its length.

2. A cable according to claim 1, **characterised** in that said means for earthing comprise a conductor connected to earth, arranged on the outside of the second semiconducting layer with an insulation sandwiched between, whereby the insulation is applied in such a way that an impulse voltage on the second semiconducting layer, which exceeds a predetermined threshold value, causing a connection of the semiconducting layer to earth due to breakdown between the second semiconducting layer and the earthed conductor.

3. A cable according to claim 2, **characterised** in that the insulation is in the form of a band made of insulating tape extending along the cable and that the earthed conductor is applied as a band divided into separated parts, arranged onto the insulating tape.

4. A cable according to claim 1, **characterised** in that said means for earthing comprise a second insulating layer,

arranged on the outside of the second semiconducting layer, and an electrically conducting outer layer connected to earth, which surrounds the second insulating layer forming a capacitance together with the second semiconducting layer, which capacitance is significantly larger than the cable capacitance.

5. A cable according to claim 1 or 2, **characterised** in that the insulation comprises an insulating tape (20) wound around the second semiconducting layer, and that the earthed conductor comprises an outer casing (26) of conducting material connected to earth, said tape being wound in separated turns with a space (22) provided between each turn and/or openings (24) are provided in the tape so that air filled spaces are formed between the second semiconducting layer (8) and the casing (8), which spaces form discharge gaps in order to divert voltage impulses from the second semiconducting layer, if their voltage exceeds a predetermined limit.

6. A cable according to claim 5, **characterised** in that the tape (20) is dimensioned such, that between the outer casing (26) and the second semiconducting layer (8) a capacitance is formed which is significantly larger than the cable capacitance.

7. A cable according to any one of claims 4-6, **characterised** in that the outer layer or the outer casing is made of metal.

8. A cable according to any one of claims 4-7, **characterised** in that the outer layer and the outer casing have circular cuts at predetermined positions along the cable.

9. A cable according to any one of claims 5-8, **characterised** in that the outer casing is in the form of separated rings (36) of electrically conducting material around the insulation, applied separated, at predetermined positions along the cable.

10. A cable according to claim 9, **characterised** in that the spaces between the rings (36) along the length of the cable exceed the width of the rings.

11. A cable according to any one of claims 1-10, **characterised** in that the electrically conducting core comprises a plurality of strands of electrically conducting material.

12. A cable according to any one of claims 1-11, **characterised** in that the diameter is within the interval 20 - 200 mm and the conductor area is within the interval 80 - 3000 mm^2.

13. A cable according to any one of preceding claims, **characterized** in that the cable is flexible.

14. A cable according to any one of preceding claims, **characterized** in that said layers are contacing each other over substantially the whole surfaces turned towards each other.

15. A cable according to any one of preceding claims, **characterized** in that said layers are adhering to each other.

16. A cable according to any one of preceding claims, **characterized** in that the materials of said layers have a high elasticity, preferable with an elasticity modulus of less than 500 MPa, preferably less than 200 MPa.

17. A cable according to any one of preceding claims, **characterized** in that the coefficients of thermal expansion for the materials of said layers are substantially of the same magnitudes.

18. A cable according to claim 15, **characterized** in that the adherence of said layers is at least of the same order of magnitude as the strength of the weakest material.

19. A cable according to any one of preceding claims, **characterized** in that said layers are made of materials of such elasticity and such coefficients of thermal expansion that, in operation, volume changes of the layers caused by variations of the temperature are absorbed by the elasticity of the materials, such that the layers maintain their abutment against each other for those variations of the temperature occurring during operation.

20. A cable according to any one of preceding claims, **characterized in** that each one of the semiconducting layers constitutes an equipotential surface.

21. An electric winding, **characterised** in that it is wound by a cable according to any one of the preceding claims.

22. A winding according to claim 21 having a cable according to claim 8, **characterised** in that one cut (30) per winding turn (28) is arranged in the outer casing of the cable.

23. A winding according to claim 22, **characterised** in that the outer casings of adjacent winding turns (28) are in contact with each other with the cuts (30) arranged in the same location for each winding turn, and in that the outer casing is earthed only at the ends of the winding, the earthing

connection at the one end of the winding being arranged to the one side of the cuts (30) and the earthing connection at the other end of the winding to the other side of the cuts.

24. A winding according to claim 21 having a cable according to claim 9, **characterised** in that the winding is designed such that the rings (36) of adjacent winding turns are in contact with one another in such a way, that the rings form at least one continuous electrical connection across the winding, which connection is earthed at the one end of the winding (at 38, 40).

25. A dry transformer, **characterised** in that it comprises at least one winding according to any one of claims 21-24.

26. A reactor **characterised** in that it comprises a winding according to any one of claims 21-24.

Fig. 1

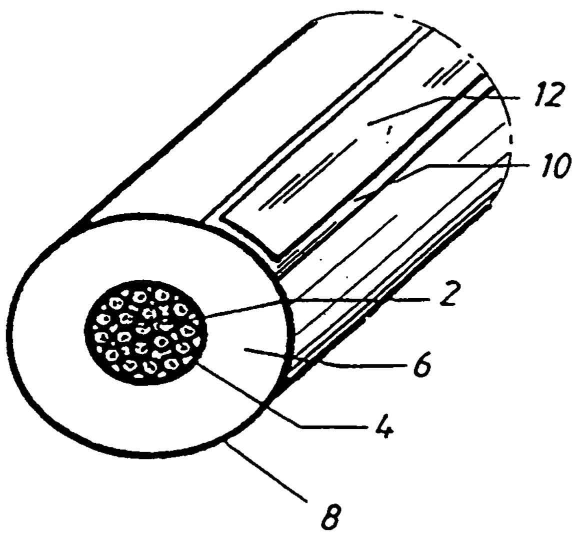
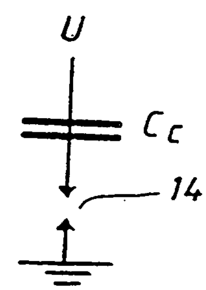


Fig. 2



(b)

Fig. 3

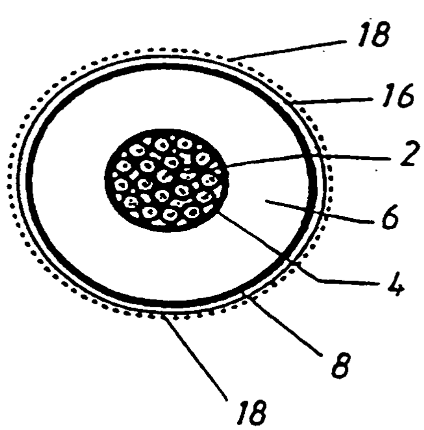


Fig. 4

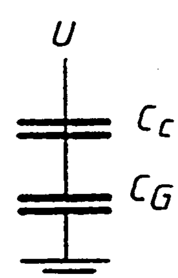


Fig. 5

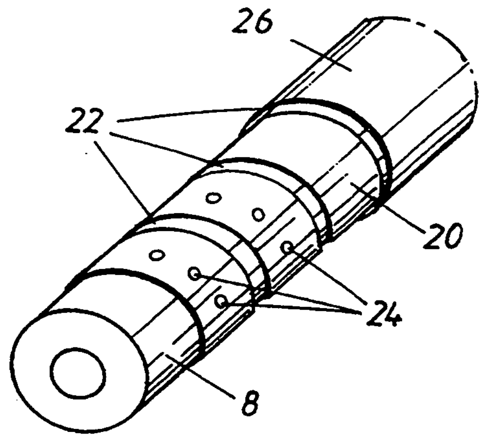


Fig. 6

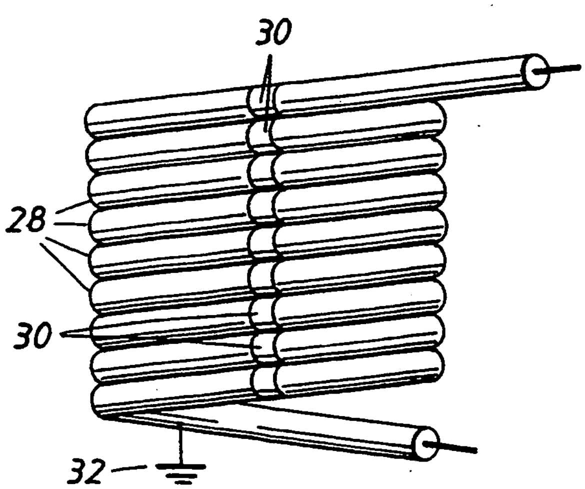
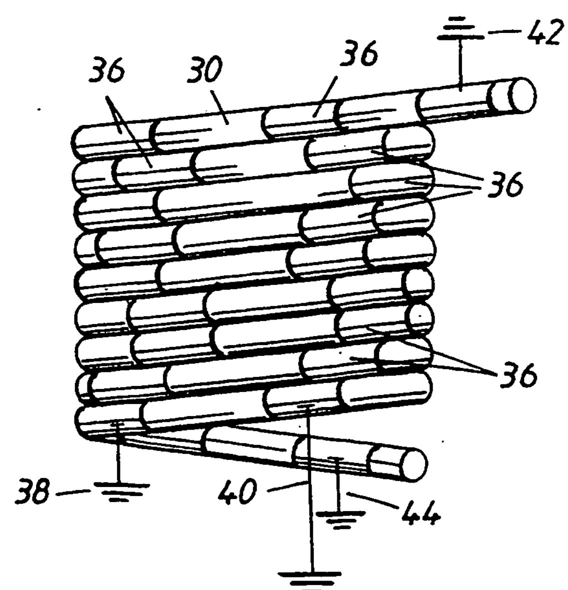


Fig. 7



INTERNATIONAL SEARCH REPORT

International application No.
PCT/SE 98/00159

A. CLASSIFICATION OF SUBJECT MATTER

IPC6: H01F 27/34
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC6: H01F

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

SE,DK,FI,NO classes as above

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EDOC, WPIL, JAPIO

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 4109098 A (MATS GUNNAR OLSSON ET AL), 22 August 1978 (22.08.78), abstract --	1
A	US 5036165 A (RICHARD K. ELTON ET AL), 30 July 1991 (30.07.91), abstract -- --------	1

☐ Further documents are listed in the continuation of Box C.   ☒ See patent family annex.

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Date of the actual completion of the international search	Date of mailing of the international search report
11 June 1998	17 -06- 1998
Name and mailing address of the ISA/ Swedish Patent Office Box 5055, S-102 42 STOCKHOLM Facsimile N . +46 8 666 02 86	**Authorized officer** Magnus Westöö Telephone No. +46 8 782 25 00

INTERNATIONAL SEARCH REPORT

Information on patent family members

29/04/98

International application No.

PCT/SE 98/00159

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